Efficacy of pre-activity stretching

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EFFICACY OF PRE-ACTIVITY STRETCHING

by

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ABSTRACT

Efficacy of Pre-Activity Stretching

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Pre-activity stretching is commonly performed by athletes as part of their warm-up routine. However, the most recent literature questions the effectiveness of pre-activity stretching. Some literature suggests that pre-activity stretching hinders athletic performance, while others suggest that stretching does not affect performance. Since a clear answer has not yet been determined on pre-activity stretching, this study was designed to investigate the acute effects of static vs. ballistic stretching on vertical jump performance, and torque and power output of the quadriceps and hamstrings, and to compare the effects of stretching between genders. The goal was to determine if pre-activity stretching is beneficial or detrimental to sports performance. The results of this study revealed that a practical duration of 90 seconds of stretching did not affect VJ or torque output of the quadriceps and hamstrings. The results of this study will allow strength coaches to properly advise their athletes on pre-activity stretching.
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CHAPTER 1

INTRODUCTION

Statement of the Problem

A popular question discussed among athletic trainers is whether or not pre-activity stretching affects sports performance. There have been numerous studies that have focused on this question, which has resulted in conflicting findings. Although there is little evidence to support the belief that stretching improves performance coaches and athletic trainers continue to encourage athletes to stretch before athletic activities.

A review of the literature revealed a number of conflicting studies. Some literature suggests that pre-activity stretching hinders athletic performance (2, 8, 15, 17, 18, 22, 23, 24, 25, 28, 36), while others suggest that stretching does not affect performance (1, 3, 4, 14, 25, 32, 35). It is evident that there is still no clear answer to how stretching affects athletic performance. One specific aspect of athletic performance that has been focused on in the research is vertical jump (VJ) performance. The results of many studies focusing on VJ conflict with others, some say that static stretching diminishes VJ (5, 18, 33, 37, 38) whereas others say that static stretching has no affect at all on VJ (3, 4, 14, 25, 32). It is clear that there is not enough consistent research to conclude the definite effects of pre-activity stretching on VJ performance. Further research is needed to determine the acute effects of stretching on VJ. A second aspect of athletic performance that has been studied is maximal strength performance. An overwhelming amount of research has

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provided consistent evidence that pre-activity stretching diminishes strength and power performance (2, 6, 8, 15, 17, 20, 22, 23, 25). However, conflicting results were found in a few studies (1, 35) which reported that acute pre-activity stretching did not affect maximum voluntary isometric contraction or power of the leg extensors.

One recent study (32) suggested that further research should be conducted to determine the acute effects of stretching on power. Unick et al (32) hypothesized that gender may affect these results and this should also be investigated. The authors suggested this because they were not able to find any current research investigating the acute effects of ballistic stretching on power. The authors also felt it is important to investigate these effects since ballistic stretching is commonly used prior to power events. During ballistic stretching the antagonist muscle is stretched by repetitive bouncing movements while the agonist muscle contracts. Athletes generally use this type of stretching to progressively prepare their muscles for dynamic contractions.

Another commonly used form of stretching, static stretching, involves slow controlled lengthening of a muscle to a tolerable limit that is held for an extended period of time. Unlike ballistic stretching static stretching does not involve muscular contraction and the end point of the stretch is held.

Since a clear answer has not yet been determined on pre-activity stretching, this study was designed to investigate the acute effects of static vs. ballistic stretching on VJ performance, power and torque output of the quadriceps and hamstrings, and to compare the effects of stretching between genders. The goal was to determine if pre-activity stretching is beneficial or detrimental to sports performance. The results of this study will allow coaches and athletic trainers to properly advise their athletes on pre-activity
stretching. Many sports require maximal power performance for success, so this information will be especially beneficial for these types of activities. This will serve as valuable information when designing a warm-up routine or rehabilitation program.
CHAPTER 2

REVIEW OF LITERATURE

Stretching as part of a warm-up routine

The majority of athletes perform some type of warm-up routine before participating in physical activities. With most conditioning programs the warm-up routine that is performed involves some form of stretching. The three most common types of stretching include static, ballistic, and proprioceptive neuromuscular facilitation (PNF). Static stretching occurs when a muscle is lengthened to a tolerable limit and is held in that position for a specified period of time. Static stretching is considered to be a safer form of stretching than ballistic because it does not involve any fast movements and is performed in a controlled manner (13, 21, 30). Ballistic stretching occurs when the muscle is lengthened and the momentum of a moving extremity tries to lengthen the muscle beyond its normal range of motion (ROM). This type of stretching consists of a subject performing repetitive bouncing movements at the involved joint.

PNF stretching utilizes the body’s reflex actions to produce an inhibitory effect on the neuromuscular system (11). The facilitation with PNF occurs through two mechanisms, autogenic inhibition and reciprocal inhibition. PNF stretching causes these inhibitory actions by stimulating mechanoreceptors. Mechanoreceptors function to send messages to the central nervous system about the condition of the muscle. Two mechanoreceptors involved with PNF stretching are the muscle spindle and the golgi tendon organ (GTO).
The GTO is stimulated when too much force is produced in the muscle for at least 6 seconds, and responds by causing a reflex relaxation of the muscle. Autogenic inhibition occurs when the antagonist muscle is contracted and stimulates the GTO, which causes relaxation of this muscle. Reciprocal inhibition occurs when the agonist muscle is contracted causing a simultaneous relaxation of the antagonist muscle. The muscle spindles are stimulated when the muscle is stretched, and responds by causing a reflex contraction of the muscle. Stimulation of the muscle spindle can be avoided with a sustained passive stretch.

There are many different reasons why athletes perform each of the 3 types of stretching as a part of their warm-up routine. Stretching has been shown to increase ROM (4, 7, 13, 15, 19, 23, 26, 31, 30, 36), improve running economy (28, 29), is believed to prevent injuries (9, 19, 27, 30) and improve performance (9, 19, 27, 30). Although many coaches and athletic trainers recommend that their athletes stretch before activity to improve performance, there is not adequate research available to support this recommendation. The most recent literature suggests that pre-activity stretching hinders athletic performance by temporarily reducing the amount of force that a muscle can produce (2, 8, 15, 17, 18, 22, 23, 24, 25, 28, 36).

**Acute stretching and muscle stiffness**

It has been shown that a stiff musculotendinous unit allows for a greater amount of force to be produced by the contractile component when compared to a compliant musculotendinous unit (34). Wilson et al (34) found that a stiff musculotendinous unit was significantly related to improved isometric and concentric performance but not to
eccentric performance. Acute stretching of a muscle can cause the musculotendinous unit to become compliant, or less stiff. This change in stiffness that is caused by acute stretching may compromise the muscle’s ability to produce maximal muscular force.

Gender differences in muscle stiffness

The ability of a muscle to effectively generate force may also be influenced by gender. Kubo et al (16) attempted to determine if any gender differences are apparent in the viscoelastic properties of the tendon structure. From this study (16) it was determined that the muscle stiffness in women was significantly lower than in men, suggesting that the musculotendinous units in women are less resistant to stretching than those of men. The authors also suggested that women dissipate a much smaller amount of elastic energy during stretch-shortening cycle exercises when compared to men. This happens because the increased musculotendinous compliance seen in women decreases the amount of stored elastic energy that is lost. All of these findings suggest that the viscoelastic properties of tendon structures are different between genders, accounting for part of the reason why men and women do not equally generate force for power performance or stretch-shortening cycle exercises.

However, in a study by Unick et al (32) 16 women performed two types of vertical jumps (VJ); countermovement jump (CMJ) and drop jump (DJ), under 3 conditions; static stretching, ballistic stretching, and no stretching. The results of this study revealed that the women’s VJ scores were not affected by the stretching conditions. A similar experimental design used by Young and Elliott (38) found that the men had a significant decline in DJ performance following static stretching but no decline was seen in the
squat-jump performance. These results supported the speculations made by Kubo et al (16) that the viscoelastic properties of tendon structures are different between genders by finding that males had greater muscle thickness than women and women had lower muscle stiffness. However, Wilson et al (34) suggested that fast movements involving the stretch-shortening cycle, such as the DJ, would benefit more from a stiff musculotendinous unit and that stretching would hinder this type of activity. From this we would have expected the 16 women from the Unick et al (32) study to suffer a decline in VJ performance especially since Kubo et al suggested that women naturally have more compliant musculotendinous units than men. These contradicting results show that further research needs to be conducted to determine the different effects that gender may have on acute stretching.

Acute stretching causes temporary strength deficit

Acute stretching does cause some immediate effects that are considered positive such as increased muscular temperature (13) and increased range of motion (ROM) (4, 7, 13, 15, 19, 23, 26, 30, 31, 36). However, recent studies (2, 8, 25) have determined that acute stretching can cause a temporary deficit in strength performance. Behm et al (2) examined the effect of a 20-minute static stretching session by measuring the maximal isometric voluntary contraction (MVIC) force of the quadriceps before the stretching session and 5-10 minutes after. The results showed that MVIC significantly decreased by 12% following the stretching session. This decrement was attributed to a simultaneous decline in muscle activation. Static stretching caused a 20% decrease in the integrated electromyographic (iEMG) activity of the quadriceps resulting in a reduced force output.
during MVIC. This finding of reduced force output and muscle activation following acute stretching is consistent with other studies (8, 10, 17).

Fowles et al (8) conducted two studies in which 10 subjects underwent 33 minutes of maximal passive static stretching of the plantar flexors. Measurements of strength included MVIC of the plantar flexors with a superimposed maximal twitch delivered ~2 seconds after maximal contraction. These measurements were taken before, immediately following and at 5, 15, 30, 45, and 60 minutes following the stretching routine. Other measurements included motor unit activation and muscle stiffness. In the first experiment Fowles et al (8) found that MVIC was significantly reduced by 28% immediately following the stretching routine. When the strength measurement was collected at 60 minutes following the stretching routine the MVIC remained 9% below the pre-stretching value. The results also showed that motor unit activation of the plantar flexors was reduced for up to 15 minutes following the stretching routine. This reduced motor unit activation was one of the causes of the reduced MVIC force. However, 15 minutes following the stretching routine activation of the plantar flexors was fully restored.

The reduction of MVIC force may also be due to the 27% decline in muscle stiffness, which most likely compromised the muscle’s ability to produce maximal muscular force. The decline in muscle stiffness also remained below the pre-stretching values when measured at 60 minutes following stretching. The authors (8) concluded that the intense stretching routine caused a reduction in the MVIC of the plantar flexors lasting up to 1 hour following stretching. The authors (8) also concluded that this reduction in MVIC was due to the impaired muscle activation and the decline in muscle stiffness, which

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diminished the force generating ability of the muscles. The results were supported by Power et al (25) who reported a temporary deficit in strength performance found following static stretching of the quadriceps and plantar flexors, which was a 9.5% decrease in MIVC force that lasted for 120 minutes.

**Effects of acute stretching on vertical jump performance**

VJ height is directly related to leg power, which means that in order to perform a VJ a person needs to effectively generate force with their legs at a rapid speed. We know that stretching causes a change in the musculotendinous unit causing it to become compliant which in turn causes a decline in the ability of the muscle to generate force (34). Several authors have questioned whether this change in the musculotendinous unit will affect VJ performance since it is a skill that depends on how fast force can be produced as opposed to how much force can be produced.

Church et al (4) conducted a study to determine the effect of different types of warm-up routines combined with stretching on maximum VJ. This study consisted of 40 women that were involved with NCAA Division 1 sports teams. Subjects were tested under 3 conditions: the first condition involved a warm-up routine that included 10 exercises of a body weight circuit, the second condition involved the same body weight circuit exercises immediately followed by static stretching of the quadriceps and hamstrings, and the third condition involved the body weight circuit exercises immediately followed by a session of PNF stretching of the quadriceps and hamstrings using the contract-relax agonist-contract method.
Subjects performed these conditions over 3 nonconsecutive days and their VJ was tested following each warm-up condition with the Just Jump system (Probotics, Huntsville, AL). The results of the study showed that the warm-up with static stretching did not cause any significant changes in VJ when compared to the warm-up only condition. However, the warm-up with PNF stretching caused a significant decrease in VJ when compared to the other two conditions. The authors believed that the difference in VJ between the three conditions was not due to changes in musculotendinous stiffness since all three conditions caused similar increases in hamstring flexibility.

It was suggested that the PNF condition caused a decrease in VJ because of a theory (15) that states repetitive stretching can cause autogenic inhibition, which reduces the available motor units to produce a muscle action. The finding that the warm-up with static stretching did not affect VJ is consistent with other studies (3, 4, 14, 25, 32).

Unick et al (32) designed a study to determine whether static and ballistic stretching had any acute effects on VJ and if this effect remained after stretching. Subjects were 16 Division III women's basketball players that performed 3 conditions on 3 separate days which included static stretching, ballistic stretching and no stretching. For the static and ballistic stretching conditions subjects performed 4 lower body stretches following a warm-up jog. After performing these conditions subjects walked for 4 minutes before performing the VJ test. Both the CMJ and a 26.5 cm DJ were tested using the Vertec VJ system (Sports Imports, Hilliard, OH). Subjects performed each of these jumps 3 times immediately following the stretching condition, and at 15 and 30 minutes after stretching.

The results showed that the static and ballistic stretching conditions did not have any affect on VJ performance. Since these results conflict with other research (5, 18, 33, 37,
the authors attempted to speculate possible reasons why the stretching conditions did not affect VJ. It was suggested that the “resting period” or 4 minutes of walking may have allowed any neural changes that had occurred as a result of the stretching to diminish and return to normal by the time the subjects performed the VJ tests. They also discussed the length of time that it took to perform the stretching conditions, which was 3 sets of 15 seconds or approximately 6 minutes. Although this routine was used to imitate a realistic amount of time that an athlete probably spends on stretching, the length may not have been long enough to cause changes in the musculotendinous unit. Another interesting explanation offered was the fact that their study involved only women. There is a lack of research that focuses only on women subjects which makes it hard to understand the results of this study (32) since there is not a great deal of literature to compare it to.

Power et al (25) attempted to determine if static stretching would cause any changes in MVIC force of the quadriceps, muscle activation, and VJ, and if these changes remained after stretching. Twelve men performed two conditions, static stretching of the quadriceps and plantar flexors and a no stretch condition. The following measurements were collected during isometric contractions: muscle inactivation, MVIC force, evoked contractile properties, and iEMG activity of the agonist and antagonistic muscle groups. Subjects also performed 2 unilateral static jumps (SJ) followed by 2 unilateral 30 cm DJ, both on a contact mat (Innervations, Muncie, IN). All of these measurements were collected before the treatment condition (static and control), immediately following the treatment condition and also at 30, 60, 90, and 120 minutes after the treatment condition. The static stretching condition caused a significant decrease in MVIC force of 9.5%. The
decline in force production remained at 120 minutes. The static stretching condition also caused a significant increase in muscle inactivation of 5.4%. The static stretching condition however did not cause a change in the DJ or SJ performance. The authors suggested that the reason MVIC and muscle activation decreased may be due to the fact that all of the measurements were collected unilaterally. Since subjects performed the VJ unilaterally, the limb would have to bear a much greater load than if performed bilaterally. The authors suggested that unilateral jumps similar to the ones performed in their study might benefit from a more compliant musculotendinous unit.

Knudson et al (14) investigated the acute effects of static stretching of the quadriceps, hamstrings, and plantar flexors using sagittal plane video. Ten men and 10 women performed two treatment conditions, stretching and no stretching. After warming up on a cycle ergometer for 3 minutes subjects performed 3 practice VJs, then performed their assigned treatment condition and finally performed 3 test VJs. The following measurements were collected for this study: deepest knee flexion angle, peak vertical velocity of the center of mass prior to take-off, duration of the eccentric phase of the jump, and the duration of the concentric phase of the jump. From this testing it was found that the static stretching routine did not cause any significant changes to any of the biomechanical variables examined. Since the results did not show any significant changes, it was believed that static stretching did not cause a significant change in the stiffness of the musculotendinous unit.

Burkett et al (3) designed a study to determine the optimal warm-up condition to improve VJ. Subjects were 29 men from a Division I football team. The study compared specific and nonspecific warm-up methods including: a sub-maximal jump warm-up
consisting of 5 countermovement jumps at 75% of their maximum jump height, a weighted jump warm-up consisting of 5 CMJ while holding dumbbells equal to 10% of their body weight, static stretching, and no warm-up. Maximal VJ height was then measured within 2 minutes of performing the warm-up conditions. It was reported that the warm-up condition to produce the highest VJ performance was the weighted jump warm-up with a mean VJ of 72 cm. The authors suggested that athletes looking to improve their VJ performance should use a specific warm-up that consists of a CMJ with some form of resistance. However, even though the other two conditions, static stretching and sub-maximal jump warm-up, did not improve the VJ they also did not negatively affect it resulting in a mean VJ of 70.21 cm and 70.33 cm respectively. When the VJ following static stretching and sub-maximal jump were compared to the no warm-up, or control condition of 69.72 cm, there were no significant differences in the VJ heights. Therefore, this study determined that static stretching did not cause a change in VJ performance.

Many studies like the ones discussed previously have manipulated several different parameters to determine the acute effects of stretching on VJ performance. Some of the parameters include type of subjects (trained and untrained), gender (men only, women only, men and women combined), treatment condition (warm-up combined with stretch, warm-up only, static stretch, ballistic stretch, PNF stretch, no stretch), type of jump (CMJ, SJ, DJ), and method of VJ height measurement (Just Jump, contact mat, sagittal plane video, and the Vertec). Although each study used varying parameters all of the previously discussed studies found that stretching did not have any diminishing effects on
VJ performance. However, there is conflicting evidence in the literature that says static stretching is detrimental to VJ performance.

Wallmann et al (33) investigated whether static stretching had any affect on VJ, which was measured using a force plate (type 9281B, Kistler Instrument Corp., Amherst, NY). Muscle activity was also recorded with EMG. Fourteen men and women walked on the treadmill for 5 minutes as a warm-up and then performed 3 baseline VJ followed by 15 minutes of sitting quietly. Subjects then performed a static stretching protocol, which consisted of three, 30-second stretches of the gastrocnemius on a slant board. Within 30 seconds of completing the stretching protocol each subject performed 3 maximal VJs. A decrease of 5.6% in VJ height after stretching when compared to pre-stretch values was reported. The pre-stretch mean VJ reported was 0.284 m, which was compared to the post-stretching mean VJ of 0.268 m. The authors also reported that the activity of the gastrocnemius recorded during a maximal VJ increased by 17.9% when measured following the static stretching routine.

Cornwell et al (5) investigated the acute effects of static stretching on two different types of VJ. This study used a SJ, which is performed with a concentric muscle action, and a CMJ, which is performed utilizing the stretch-shortening cycle. Ten men performed both types of VJ on a force platform (AMTI, Newton, MA) following each treatment condition. The treatment conditions included static stretching of the knee and hip extensors and sitting quietly for 10 minutes. After completing a treatment condition one of the VJ was performed for 3 trials, and there was a period of 10 minutes before the second VJ was performed. SJ and CMJ height decreased significantly following static stretching when compared to the control. Static stretching also caused a significant
decrease in peak power produced during both SJ and CMJ. It was concluded that the severity of performance decrement caused by static stretching would depend on the type of athletic activity. The stretching routine decreased the SJ height by 1.0 cm, and the CMJ height by 1.2 cm. This decline in height might not severely affect some activities, but could be very detrimental for athletes that depend on maximum height performance.

Young and Elliott (38) investigated whether or not stretching and MVIC had an affect on jumping performance and peak force production. Fourteen men were tested under the following conditions: static stretching, PNF stretching, MVIC and a control condition. Subjects completed a 5 minute jog as a warm-up and then performed one of the 4 treatment conditions over a 4 day period. The MVIC, static and PNF stretching were performed on the triceps surae, gluteals, and quadriceps muscles. Three sets of the MVIC were performed for 5 seconds each followed by a 30 second rest. Static stretches were completed with 3 sets held for 15 seconds followed by a 20 second rest. For the PNF stretches the contract-relax method was used, subjects performed a 5 second MVIC followed by a 15 second passive stretch which was repeated 3 times. The control condition consisted of 4 minutes of resting. After completing the treatment subjects then walked for 4 minutes before performing the two VJ tests. This study used a SJ and a DJ to assess force production and jump performance. The SJ was used because it only utilizes concentric muscle actions. To perform this jump subjects had a 10 kg bar placed on their shoulders. They assumed a squat position with their knee angle at 100° and held this position for 2 seconds, and then jumped up as fast as possible to obtain maximum vertical height. Subjects performed this jump 4 times, once for practice and 3 times for measurement on a force platform (Z4852/C, Kistler, Winterthur, Switzerland).
The second jump, DJ, was performed because it utilizes the stretch-shortening cycle. Subjects stood on a 30 cm box with hands on hips and stepped off the box with one fully extended leg. Once subjects landed they were instructed to jump up as fast as possible to obtain maximum vertical height. This jump was also performed 4 times, once for practice and 3 times for measurement on a contact mat system.

It was found from this testing procedure that the static stretching routine caused a significant decrease in DJ performance when compared to the other 3 treatments. For the SJ there was no significant difference found in jump performance between the four treatments. The authors cited previous research (34) that suggested that stretching would improve movements that involve the stretch shortening cycle because increased muscle compliance was beneficial for these movements. This was not the case however in this study. In fact the only movement affected by the static stretching was the DJ, which involves the stretch shortening cycle, and this was negatively affected. The authors suggested that a reason for this is that the DJ that was used in this study required quick movements, which would benefit from increased musculotendinous stiffness. This study also found that the PNF and MVIC treatment did not have any beneficial affects on jump performance or peak force production.

Young and Behm (37) investigated the effects of different types of warm-ups involving static stretching, running, and practice jumps on jump performance and force production. Thirteen men and 3 women completed 5 different types of warm-up. The first condition was 4 minutes of running at a self-selected pace. The second condition was static stretching in which subjects performed 2 stretches for the plantar flexors and 2 stretches for the quadriceps for 2 sets of 30 seconds. The third condition included both

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the running condition and the stretching condition. The fourth condition included the running condition, stretching condition and also 4 practice jumps. Subjects performed SJ and DJ, the same two jumps used for testing, 4 times each with 1 jump performed at 80% maximum effort and the other 3 jumps at 100% effort. The VJ used in this study was the same used by Young and Elliott (38). The final condition was a control in which subjects walked for 3 minutes and then performed 5 squats and 5 heel raises. After completing the warm-up treatment subjects then stood resting for 2 minutes before performing the 2 VJ tests. The SJ and DJ tests were performed over three trials.

The results showed that the two best warm-up methods were running only and the running, stretch, and practice jumps combined condition. These two methods resulted in the greatest force production and jump performance. Another finding was that the static stretching only condition produced the worst force production and jumping performance when compared to the other 4 conditions. The other condition, running with stretching, did not cause any detrimental changes to force production or jump performance, but resulted in performance similar to the control. These results that show static stretching caused a decrease in VJ performance conflict with the results of Burkett et al (3) that found a static stretching routine of 14 stretches each held for 20 seconds did not negatively affect VJ performance. Young and Behm (37) concluded that when jumping movements are involved athletes should choose a warm-up that involves a practice of the activity to be performed combined with a sub-maximum run instead of static stretching to positively influence performance.

Stretching is commonly recommended and utilized in the adult population when sports are involved. Children, especially those involved in sports that require extreme
flexibility such as gymnastics, also utilize stretching. McNeal et al (18) designed a study to determine if the acute effects seen with adults and static stretching were also prevalent in children. Thirteen girls who were gymnasts completed two treatment conditions, static stretching of the gastrocnemius and hamstrings and a no stretch condition. After completing one of the treatment conditions subjects then performed 3 DJ onto a timing mat (NEWTEST Power timer 1.0, Kiviharjuntie, Finland), which assessed time in air and floor contact time. It was found from this study that the static stretching routine caused a significant mean decrease of 9.6% in jump performance. The time in air was significantly decreased post stretching, but the stretching did not affect the contact time. These findings support recent literature (5, 15, 17, 18, 33, 37, 38) involving adult subjects that show acute static stretching causes decrements in power and jumping performance.

Based on the literature reviewed it is evident that there is still no clear answer to how stretching affects VJ performance. The results of many studies conflict with others, some say that static stretching diminishes VJ performance (5, 18, 33, 37, 38) whereas others say that static stretching has no affect at all on VJ (3, 4, 14, 25, 32). It is clear that there is not enough consistent research to conclude the definite effects of stretching on VJ performance. Further research is needed to determine the acute effects of stretching on VJ performance.

Acute stretching and its effects on generation of torque and power

Stretching is commonly promoted as a beneficial aspect of the warm-up before physical activity; however there is little scientific research to support the belief that stretching improves athletic performance. Research does suggest that stretching on a
regular basis may improve athletic performance (12, 29); this however does not apply to acute stretching directly before performing strength and power activities.

Kokkonen et al (15) examined the effect of acute static stretching on maximal strength performance. Fifteen men and 15 women performed two treatment conditions, static stretching and no stretching. For the static stretching condition 20 minutes of stretching was performed on the thigh, hip, and calf muscle groups. For the no stretch condition subjects sat quietly for 10 minutes. Flexibility was measured with a sit-and-reach test prior to and immediately after treatment. Strength performance was measured with a 1-repetition maximum prone knee flexion and knee extension exercise with a 10-15 minute rest between each test. The static stretching protocol caused a significant 7.3% decrease in 1-repetition maximum knee flexion, and an 8.1% decrease in 1-repetition maximum knee extension when compared to the no stretch condition. The results also showed that the static stretching protocol caused a significant 16% increase in flexibility. The authors concluded from these results that the mechanism for reduced strength performance might be due to a change in the stiffness of the musculotendinous unit. It was believed that the 20 minute static stretching protocol did cause changes in the musculotendinous units since the flexibility was significantly increased by 16%. The authors suggested that static stretching should not be performed preceding an activity that requires maximal strength production.

Based on the results of Kokkonen et al (15), Nelson and Kokkonen (23) designed a similar study to determine if ballistic stretching would cause equal effects on force production as static stretching. Subjects were 11 men and 11 women. The experimental design for this study was the same as the one used by Kokkonen et al (15). The only
difference was that subjects experienced two treatment designs, no stretch and ballistic stretching. Subjects reported for these treatments on consecutive days. For the no stretch condition subjects sat quietly for 10 minutes. For the ballistic condition subjects performed 5 different stretches focusing on the thigh, hip and calf muscles. Each stretch was performed 3 times assisted by the examiner and 3 times unassisted. Strength was measured with a 1-repetition maximum prone knee flexion and knee extension exercise with 10-15 minute rest between tests. The results showed that the ballistic stretching routine significantly decreased the 1-repetition maximum for knee flexion by 7.5% and for knee extension by 5.6%. The authors concluded that ballistic stretching does have the same effects on maximal strength performance as static stretching and should not be performed before maximal strength activities. The authors also concluded that the same mechanism, reduction in musculotendinous stiffness, might be to blame for these two stretching-induced decrements.

Marek et al (17) examined the acute effects of both static and PNF stretching on strength and power performance. Ten women and 9 men performed a static and PNF protocol for the leg extensors with 4 stretches. Each static stretch was held for 30 seconds and repeated 4 times. The PNF method used was contract-relax, where subjects performed a 5 second maximal isometric muscle action of the leg extensors and then a passive stretch for 30 seconds. The PNF method was repeated 4 times for each stretch. The following measurements were collected, peak torque, and mean power output. Peak torque and mean power output were collected. Peak torque was measured on an isokinetic dynamometer using a concentric knee extension at 60°/s and 300°/s. The results of this study showed that both the static and PNF protocols caused a significant
decrease in peak torque and mean power output at both velocities of 60°/s and 300°/s when compared to the pre-stretch values. The authors concluded that stretching prior to strength and power activities of the leg extensors will diminish performance, and that this stretching-induced decrement is possibly not velocity-specific.

Cramer et al (6) used 14 women to determine if a static stretching routine had any detrimental effects on concentric peak torque production. The concentric peak torque was measured on an isokinetic dynamometer before and after the stretching routine. Subjects performed 3 sub-maximal knee extensions to serve as a warm-up and 3 maximal knee extensions at 60°/s and 240°/s for the test. The non-dominant leg of each subject served as the control. Subjects performed 4 sets of quadriceps stretches with each stretch held for 30 seconds. Subjects then sat quietly for 4 minutes before isokinetic testing of their dominant leg. The non-dominant leg was then tested 5 minutes after the dominant leg. From this study it was found that the peak torque was significantly reduced following the static stretching routine at both velocities. The peak torque at 60°/s was reduced by 3.3% and by 2.6% at 240°/s. These results conflict with that of Nelson et al (22) who found that acute static stretching causes stretching-induced decrements that are velocity specific, only affecting force production at slower velocities. Cramer et al (6) concluded that static stretching causes impairments in maximal force production and that static stretching should be reconsidered as a part of the warm-up process.

Many studies have investigated the effects of acute stretching on muscular strength performance. It is known that maximal muscular strength is connected to muscular endurance. However, few studies have been able to thoroughly establish a connection that stretching has the same affect on endurance that is does on strength. Nelson et al
(24) designed two different experiments to determine the acute effects of stretching on muscular endurance and to establish reliability. For both experiments subjects underwent two treatment conditions, static stretching and no stretching. For the static stretch condition subjects performed two different stretch exercises focusing on the hip, thigh and calf muscles repeated 8 times with each stretch held for 30 seconds. For the no stretch condition subjects sat quietly for 10 minutes. Subjects sat and rested for 10 minutes following the treatment. For the muscular endurance test each subject performed prone knee flexion movements to the beat of a preset metronome, and completed as many lifts as possible through their full available range of motion. For experiment 1, days 1 and 2, the weight was set to 60% of body weight, days 3 and 4 were completed 3 – 4 months later and the weight was set to 40% of body weight. For experiment two, on all 4 test days, the weight was set to 50% of body weight. The first experiment found that the 60% workload endurance test following stretching decreased the average amount of lifts by 24.4%. The 40% workload endurance test, or mean number of lifts, decreased by 9.8% following the static stretching condition. The second experiment performed at 50% workload also decreased in performance by 28% following stretching. The results of these two experiments clearly show that the static stretching protocol had detrimental effects on muscle strength endurance performance. The authors speculated that the static stretching caused a decrease in the available motor units causing muscle activation to diminish resulting in a decline in performance.

Nelson et al (20) conducted a study to determine if the acute effects of static stretching are specific to knee joint angles. Thirty women and 25 men performed two trials of MVIC with the knee extensors of their dominant leg, once as a baseline
measurement and following stretching. Subjects completed passive static stretching of the quadriceps by performing 2 stretches, each held for 30 seconds and repeated 4 times. MVIC were performed 4 times at 5 different knee joint angles 90°, 108°, 126°, 144°, and 162°. The authors hypothesized that acute static stretching would only have diminishing affects on MVIC performed at angles close to full extension or 180°. The results showed that the first four joint angles, 90°, 108°, 126°, and 144° produced similar MVIC torques during pre-stretch and post stretch measurements. Therefore, the stretching protocol did not diminishing torque production of the knee extensor muscles at the aforementioned angles. However, the stretching protocol did cause a decrease in the MVIC produced at the angle of 162° by 7% when compared to the pre-stretch value. This study found that stretch-induced detriments in performance are joint-angle specific, affecting the ability of the quadriceps to maximally generate force close to terminal extension.

Another study (22) conducted to determine if stretching-induced decrements occur under certain conditions investigated the ability to maximally generate torque at 5 different velocities. Ten men and 5 women volunteered for this study. Maximal concentric torque of the knee extensors was measured at two separate occasions, pre-stretching to acquire baseline measurements, and post stretching to determine the effect of the stretching protocol on force generation. Subjects performed 1 warm-up stretch and 3 passive stretches of the dominant quadriceps, held for 30 seconds and repeated 4 times. Subjects then performed maximal knee extension at 5 different velocities, 1.05, 1.57, 2.62, 3.67, and 4.71 rad/s, 4 times for each velocity. The range of motion used began at the knee joint angle of 110° and ended at 0°. Following the stretching protocol the movement velocities of 2.62, 3.67, and 4.71 rad/s resulted in similar torque production as
the baseline values. Therefore, the stretching protocol did not decrease maximal voluntary concentric torque production at these velocities. Maximal torque produced at 1.05 rad/s following stretching was significantly reduced by 7.2% when compared to the baseline values. Also maximal torque produced at 1.57 rad/s following stretching was significantly reduced by 4.5% when compared to the baseline values. The authors concluded from this study that a protocol of static stretching performed prior to slower velocity activities will hinder maximal concentric torque production and therefore should be reconsidered.

Other research that is consistent with the previous discussed studies (6, 15, 17, 20, 22, 23) include Behm et al (2) who found that static stretching caused a 12% decrease in the MVIC of the quadriceps, Fowles et al (8) reported a 28% decrease in MVIC following prolonged stretching of the plantar flexors and Power et al (25) concluded that a static stretching protocol significantly decreased quadriceps MVIC by 9.5%. An overwhelming amount of research has provided consistent evidence that pre-activity stretching diminishes strength and power performance. However, there is conflicting results found from a few studies.

Behm et al (1) investigated the acute effects of stretching on the MVIC of the leg extensors, static balance, movement time of the dominant lower limb, and reaction time. Sixteen men performed both treatment conditions of static stretching and no stretching. The static stretching condition consisted of 3 stretches focusing on the quadriceps, hamstrings, and plantar flexors with each stretch held for 45 seconds and repeated 3 times. The no stretch condition consisted of the subject resting for 26 minutes. The results showed that the static stretching protocol did not significantly affect force output.
when compared to the control condition. In fact, both the control and stretching condition caused non-significant decreases in MVIC of 5.6% and 6.9%, respectively. The authors speculated that the stretching protocol used in this study did not significantly affect force output because each muscle was only stretched 135 seconds compared to other studies that stretched 15-30 minutes. The stretching condition did however cause significant impairments to the static balance performance, movement time and reaction time.

A more recent study investigated the difference in the effect of static stretching and dynamic stretching on leg extension power. Yamaguchi and Ishii (35) proposed that the suggested mechanisms responsible for stretch-induced decrements, neurological and mechanical changes, do not remain after a 30 second stretch. They also proposed that previous studies that have used a variety of durations of stretch, 100 seconds to 30 minutes, are not realistic to what is actually performed during different methods of warm-up. Because of this they designed a study to determine the effects of a 30 second stretch. Subjects went through all 3 treatment conditions, static stretching, dynamic stretching, and no stretching. The static stretching consisted of 5 stretches focused on the plantar flexors, hip extensors, knee flexors, hip flexors and knee extensors. Each stretch was performed one time bilaterally and held for 30 seconds. The dynamic stretching also focused on the plantar flexors, hip extensors, knee flexors, hip flexors and knee extensors. The dynamic stretching consisted of subjects contracting the antagonist of each of the previous mentioned muscles one time every 2 seconds. This was completed 5 times slowly and 10 times as fast and as explosive as possible without causing any bouncing movements. For the control condition subjects could sit or lay quietly for 500
seconds. Leg extension power was assessed before and after each treatment condition. The leg extension power measured following stretching was not significantly different from the non-stretching values. The dynamic stretching protocol did however cause a significant increase in leg extension power for every subject. This study found that static stretching of the target muscles for a one time 30 second duration will not affect power performance. The authors concluded that power performance would benefit if dynamic stretching is added to the warm-up routine.

The aforementioned studies show that the research on pre-activity stretching and its effects on performance are still inconsistent. One of the reasons for inconsistent results is that studies use so many different parameters, such as type of stretching, duration of stretching, sets/reps, and measurement of performance. Further research is needed to establish a consistent conclusion on whether or not athletes should perform pre-activity stretching. In order to accomplish this future research should attempt to design parameters that mimic an athlete’s routine.
CHAPTER 3

METHODOLOGY

Purpose

The purpose of this study is two-fold: to investigate the acute effects of static vs. ballistic stretching of the quadriceps and hamstrings on vertical jump (VJ) height, lower extremity power and torque output of the quadriceps and hamstrings, and to compare the effects of stretching between genders. A randomized, counterbalanced, mixed-model experimental design will be used for this study.

Participants

Twenty-four healthy university students (12 male, 12 female; age = 22 ± 2.8 years, height = 168 ± 7.8 cm, weight = 75 ± 18.2 kg) volunteered to participate in the study. Subjects reported to the UNLV Sports Injury Research Center (SIRC) for an orientation session where they read and signed an informed consent form and completed a health screening questionnaire. The subjects that were considered medically eligible based on the results of the health screening questionnaire were invited to participate in the study. These methods have been approved by the university's institutional review board.
Participant Preparation

Once these forms were completed the subject's height, weight, and dominant leg were assessed and recorded. Dominant leg was determined by the subjects' preferred kicking leg and it was determined that all subjects were right leg dominant. Subjects were then taken through a familiarization process of the testing procedures. This included a demonstration of all treatment conditions and testing procedures. Subjects were given time to practice these procedures and ask any necessary questions. During the orientation all necessary information for testing procedures was collected, i.e. example chair positioning and range of motion limits. After completing the orientation session subjects returned to the lab for testing 3 days later.

Data Collection

Subjects returned to the SIRC to perform three different treatment protocols over 3 separate days with 48 hours between treatments. The three treatments included static stretching, ballistic stretching and a no stretch control condition. Subjects began by warming up for 5 minutes on a treadmill at a self selected speed ranging from 3.0 to 3.5 mph. Subjects then performed two different lower body static stretches focusing on the quadriceps and hamstrings. Subjects performed 3 repetitions for each stretch with each repetition lasting for 30 seconds, determined by the examiner using a stop watch. This stretching protocol took approximately 3 minutes for each muscle group. The stretching techniques were demonstrated to the subjects before the protocol to ensure that they performed them properly throughout the experiment.
The following static stretches were performed: unilateral standing quadriceps stretch and unilateral seated hamstring stretch. To perform the unilateral standing quadriceps stretch subjects stood on one leg with a posterior pelvic tilt, and with one hand against a wall for balance. Subjects grasped their foot to bring the knee into flexion as far as possible, keeping the thigh perpendicular to the floor, until a strong stretch sensation was felt in the quadriceps. All subjects were able to perform this stretch so that a strong stretch sensation was felt. To perform the unilateral seated hamstring stretch subjects were instructed to sit on an examining table with an anterior pelvic tilt, with the involved leg extended and the knee of the uninvolved leg flexed in a figure four position. Subjects then leaned forward flexing the hip and reached with their hand toward their toes until a strong stretch sensation was felt in the hamstrings.

For ballistic stretching, subjects performed the same stretches as previously described. However, instead of holding the stretch subjects were instructed to get into the specific stretch position until a strong stretch sensations was felt. Within 2 seconds of feeling a stretch sensation subjects bounced through the movement at the end of the ROM at a rate of 1 bounce per second for a total of 30 seconds. To perform the ballistic stretching a metronome was set at 60 bpm, and subjects bounced to the beat of the metronome. When stretching the quadriceps subjects flexed the knee until a strong stretch sensation was felt, and then extend the knee to the point where the stretch sensation was no longer felt. Subjects flexed and extended the knee rhythmically to the metronome. When stretching the hamstrings subjects flexed the hip while reaching towards their toes until a strong stretch sensation was felt, and then extended the hip by bouncing backwards to the point where the stretch sensation was no longer felt. Subjects
bounced forward with hip flexion and backwards with hip extension rhythmically to the metronome.

For the no stretch control condition subjects only completed the warm-up by walking for 5 minutes on the treadmill. Upon completion of the 5 minute warm-up, subjects were immediately tested for VJ.

Subjects performed 3 countermovement jumps (CMJ) on a Kistler force plate (type 9281B, Kistler Instrument Corp., Amherst, NY). The force plate was used to measure ground reaction forces (GRF) at a sampling frequency of 1,000 Hz. The GRF were measured once the subjects stepped on the force plate, while the subjects performed the CMJ and stopped recording once the subjects stepped off. This included collection of the forces produced during the CMJ which was used to calculate power and VJ height. Subjects were instructed to stand on both feet and lower their body towards the ground by moving into flexion at the knee, hip and trunk while extending both shoulders. The degree of flexion was determined by each subject based on the degree they felt they needed to flex in order to perform a maximum VJ. When subjects comfortably reached this point of flexion they instantly jumped up as high as possible while reaching for the Vertec VJ system (Sports Imports, Columbus, OH) with their dominant hand. The Vertec VJ system is a diagnostic tool that is used to measure vertical jump height. Subjects jumped up and hit the highest marker possible; the VJ height was determined from the highest moved marker. GRF were recorded for each jump with the force plate, and the peak VJ height of each testing session was determined through the following method. The sum of all forces produced during the CMJ was calculated from time 1 to time 2, to determine the take-off velocity through the following equation:
\[ F \Delta t = m \Delta v \]

In the equation, \( F \) is the sum of all forces, \( t \) is time, \( m \) is mass, and \( v \) is vertical velocity at take-off. Time 1 was identified as the point after the jump was initiated and the point when GRF equaled body weight. Time 2 was identified as the point when GRF decreased to equal body weight just before take-off. Take-off was identified as the point when GRF fell to zero. Take-off velocity was used to determine the VJ height through the following equation:

\[ mgh = \frac{1}{2} mv^2 \]

In the equation, \( g \) is the acceleration due to gravity, and \( h \) is VJ height. Power was determined by calculating work, which is the product of the sum of all forces and vertical velocity at take-off. The 3 VJ peak heights and power values were recorded.

Immediately following VJ testing subjects began torque output testing on the Biodex System 3 Dynamometer (Biodex Medical Systems, Inc, Shirley, NY) to measure torque output for the quadriceps and hamstring muscles. To ensure reliable measurements, the dynamometer was calibrated, and all stabilization straps were used to prevent unwanted movement. Each subject was positioned in the chair so that the axis of rotation of the dynamometer lined up with the joint line of the involved knee. This position was assessed and recorded during the orientation session so that subjects were able to go straight from VJ testing to Biodex testing. Subjects were instructed to place their hands on the stabilization handles during testing. Subjects performed 3 maximal concentric muscle actions for knee extension and flexion at 60°/second. Subjects performed these movements through a range of motion of 105° flexion and 10° extension (0°= full
extension). The peak torque of these 3 maximal repetitions was recorded for each muscle group.

**Statistical Design**

For each dependent measure, the largest recording was used for the analysis. For example the largest peak torque produced by the quadriceps and hamstrings under each condition was used for analysis. The highest VJ as determined by the highest moved marker on the Vertec VJ system was also used for analysis as was the VJ calculated from the force plate. Finally, peak power as calculated from GRF recorded by the force plate was used for analysis. Data normalized for body weight were analyzed using five separate, 3 (Stretch Condition) x 2 (Gender) analysis of variance (ANOVA) procedures with repeated measures on the first factor (Stretch Condition).
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APPENDIX 1

ACUTE EFFECTS OF STATIC AND BALLISTIC STRETCHING ON MEASURES OF STRENGTH AND POWER
Abstract

Athletes commonly perform pre-activity stretching as part of their warm-up routine. However, the most recent literature questions the effectiveness of pre-activity stretching. One limitation of this research is that the stretching duration is not realistic for most athletes. Therefore, the purpose of this study was to determine the effects of a practical duration of acute static and ballistic stretching on vertical jump (VJ), lower extremity power, and quadriceps and hamstring torque. Twenty-four subjects (12 men, 12 women; age = 22 ± 2.8 yrs, height = 168 ± 7.8 cm, body mass = 75 ± 18.2 kg) participated. Subjects performed a 5 minute warm-up followed by one of the following conditions with order counterbalanced: static stretching, ballistic stretching, or no stretch control condition. VJ was determined with the Vertec VJ system, and also calculated from the ground reactions forces collected from a Kistler force plate, which were also used to calculate power. Torque output of the quadriceps and hamstrings was measured through knee extension and flexion on the Biodex System 3 Dynamometer at 60°/s. Data normalized for body weight were analyzed using five separate, 3 (Stretch Condition) x 2 (Gender) analyses of variance (ANOVA) procedures with repeated measures on the factor Stretch Condition. The Gender x Stretch interaction was not significant for any of the 4 measures above suggesting that the stretching conditions did not affect men and women differently. The results of this study revealed that static and ballistic stretching did not affect VJ, or torque output for the quadriceps and hamstrings. Despite no adverse affect on VJ, stretching did cause a decrease in lower extremity power, which is surprising. Due to the mixed results, strength coaches would be better served to use
dynamic stretching prior to activity which has been consistently supported by the literature.

KEY WORDS: Vertical jump, torque, flexibility, performance

Introduction

Stretching prior to physical activity has been a popular practice performed by athletes for many years. Strength coaches commonly recommend pre-activity static stretching for their athletes without knowing how this will affect their sports performance. This recommendation has been based on the idea that stretching enhances performance (10, 18, 25, 28) prevents injury (10, 18, 25, 28) and increases flexibility (3, 6, 12, 14, 18, 21, 24, 28, 29, 35). Recent research has shown that there is not much scientific evidence to support this practice. Many authors have reported that stretching prior to physical activity is in fact detrimental to sports performance, especially when this performance requires maximal force production (1, 5, 9, 14, 16, 19, 20, 21, 23). The most recent literature suggests that pre-activity stretching hinders athletic performance by temporarily reducing the amount of force that a muscle can produce (1, 9, 14, 16, 17, 20, 21, 22, 23, 26, 35).

Many authors have speculated that this stretch induced decrease is caused by a reduction of musculotendinous (MTU) stiffness, which reduces the muscle’s ability to effectively generate force (14, 21). It has been shown that a stiff MTU allows for greater force production by the contractile component when compared to a compliant MTU (32). However, this research is not consistent with others and has been challenged by findings that stretching does not affect sports performance. Church et al (3) found that static
stretching did not affect vertical jump (VJ), but did however decrease MTU stiffness since the static stretching routine caused a significant increase in hamstring flexibility. Unick et al (30) investigated the acute effects of static and ballistic stretching on VJ and found that neither stretching routine affected performance. Burkett et al (2) found that a static stretching routine did not cause any significant changes to VJ when compared to the control condition. A review of the current literature shows that the results of many studies conflict with others, some suggest that static stretching diminishes VJ performance (4, 17, 31, 36, 37) whereas others suggest that static stretching has no affect at all on VJ (2, 3, 13, 23, 30). It is clear that there is not enough consistent research to firmly establish the effects of stretching on sports performance. Therefore, the purpose of this study was two-fold: to investigate the acute effects of a practical duration of static and ballistic stretching of the quadriceps and hamstrings on VJ, lower extremity power and torque output of the quadriceps and hamstrings, and to compare the effects of stretching between genders.

**Methods**

**Experimental Approach to the Problem**

A randomized, counterbalanced, mixed-model experimental design was used to determine the effects of static and ballistic stretching on measures of strength and power. The three dependent variables were VJ height, power, and torque. This design was able to test whether pre-activity static and ballistic stretching affects performance. This design also allowed the authors to establish if a difference exists with the effects of stretching between men and women.
Subjects

Twenty-four healthy university students (12 men, 12 women; age = 22 ± 2.8 yrs, height = 168 ± 7.8 cm, body mass = 75 ± 18.2 kg) volunteered for the study. All subjects were screened for previous injuries to the lower extremity prior to participation. The university’s institutional review board gave approval for all procedures. Subjects were required to report to a research laboratory to read and sign a medical questionnaire and an informed consent. Subjects performed three different stretching protocols with order counterbalanced over 3 separate days with 48 hours between testing. The three protocols included static stretching, ballistic stretching and a no stretch control condition.

Procedures

Subjects were required to attend an orientation session in which they were familiarized with the testing procedures. Three days following familiarization subjects returned for testing. On each testing day subjects performed a 5 minute warm-up on a treadmill at a self selected speed ranging from 3.0 to 3.5 mph. This was immediately followed by one of the three stretching conditions. Subjects performed two different lower body static stretches focusing on the quadriceps and hamstrings. VJ and lower extremity power were determined with a countermovement jump (CMJ) that was performed on a Kistler force plate (type 9281B, Kistler Instrument Corp., Amherst, NY) approximately 30 seconds following stretching. VJ was simultaneously measured with the Vertec VJ System (Sports Imports, Columbus, OH). Torque was assessed for the quadriceps and hamstrings using the Biodex System 3 Dynamometer (Biodex Medical Systems, Shirley, NY).
Stretching Protocols

Subjects performed 3 repetitions of each stretch with each repetition lasting 30 seconds, which was timed by the examiner. The stretching techniques were demonstrated to the subjects before the protocol to ensure proper performance throughout the experiment. The following static stretches were performed: unilateral standing quadriceps stretch and unilateral seated hamstring stretch. To perform the unilateral standing quadriceps stretch subjects stood on one leg with a posterior pelvic tilt, and with one hand against a wall for balance. Subjects grasped their foot to bring the knee into flexion as far as possible, keeping the thigh perpendicular to the floor, until a strong stretch sensation was felt in the quadriceps (Figure 1). All subjects were able to perform this stretch so that a strong stretch sensation was felt. To perform the unilateral seated hamstring stretch subjects were instructed to sit on an examining table with an anterior tilt of the pelvis, with the involved leg extended and the knee of the uninvolved leg flexed in a figure four position. Subjects then leaned forward flexing the hip and reached with their hand toward their toes until a strong stretch sensation was felt in the hamstrings (Figure 2).

For ballistic stretching, subjects performed the same stretches as previously described. However, instead of holding the stretch subjects were instructed to get into the specific stretch position until a strong stretch sensation was felt. Within 2 seconds of feeling a stretch sensation subjects bounced through the movement at the end of range of motion (ROM) at a rate of 1 bounce per second for a total of 30 seconds. To perform the ballistic stretching a metronome was set at 60 bpm, and subjects bounced to the beat of the metronome. When stretching the quadriceps, subjects flexed the knee until a strong
stretch sensation was felt, and then extended the knee to the point where the stretch sensation was no longer felt. Subjects flexed and extended the knee rhythmically to the metronome within the identified range. When stretching the hamstrings, subjects flexed at the hip while reaching toward their toes until a strong stretch sensation was felt, and then extended at the hip to the point where the stretch sensation was no longer felt. Subjects bounced forward with hip flexion and backward by hip extension rhythmically to the metronome within the identified range.

For the no stretch control condition, subjects only completed the warm-up by walking for 5 minutes on the treadmill, then subjects immediately began VJ testing.

**VJ and Power testing**

VJ height was assessed with the force plate and Vertec VJ system, and lower extremity power was assessed with the force plate. Subjects performed 3 CMJ’s on each day following their stretching condition. Subjects were instructed to stand on both feet on the force plate and lower their body toward the ground by moving into flexion at the knee, hip and trunk while extending both shoulders (Figure 3). When subjects comfortably reached this point of flexion they instantly jumped up as high as possible while reaching for the Vertec VJ system with their dominant hand. Subjects jumped up and hit the highest marker possible on the Vertec (Figure 4). The VJ height was determined from the highest moved marker. Ground reaction forces (GRF) were recorded for each jump with the force plate. The highest VJ determined by the Vertec VJ system from each testing session was recorded. The height of this jump was also calculated using the GRF recorded by the force plate through the following method. The sum of all forces produced during the CMJ was calculated from time 1 to time 2, to
determine the take-off velocity through the following equation:

$$FAt = m\Delta v$$

In the equation, $F$ is the sum of all forces, $t$ is time, $m$ is mass, and $v$ is vertical velocity at take-off. Time 1 was identified as the point after the jump was initiated and the point when GRF equaled body weight. Time 2 was identified as the point when GRF decreased to equal body weight just before take-off. Take-off was identified as the point when GRF fell to zero. Take-off velocity was used to determine the VJ height through the following equation:

$$mgh = \frac{1}{2}mv^2$$

In the equation, $g$ is the acceleration due to gravity, and $h$ is VJ height. Power produced during this jump was determined by calculating work, which is the product of the sum of all forces and vertical velocity at take-off ($Fv$).

**Torque output testing**

Each subject was positioned on the Biodex chair so that the axis of rotation of the dynamometer lined up with the joint line of the right knee. The lower leg was strapped to the dynamometer lever arm approximately two finger widths above the medial malleolus. To ensure reliable measurements, the dynamometer was calibrated, all stabilization straps were used to prevent unwanted movement, subject’s hands were required to remain free, and no visual feedback was provided during testing. Subjects performed 3 maximal isokinetic concentric muscle actions for knee extension and flexion at 60°/second through a 10 – 105° range of movement ($0° = $ full knee extension) (Figure 5). The highest peak torque from the 3 maximal repetitions was recorded for each muscle and used in the analysis.
Statistical Analyses

For each dependent measure, the largest recorded value from the 3 repetitions was used for the analysis. For example, the largest peak torque produced by the quadriceps and hamstrings under each condition was used for analysis. Data normalized for body weight were analyzed using five separate, 3 (Stretch Condition) x 2 (Gender) analyses of variance (ANOVA) procedures with repeated measures on the factor Stretch Condition.

Results

The statistical analyses yielded very similar results across measures. These measures and their respective results are detailed below.

VJ – Calculated: The main effect for stretch condition on VJ as measured by the force plate was not significant, $F_{1,22} = .660, p = .425$. The main effect for gender was significant, $F_{1,22} = 67.645, p < .001$. The Gender x Stretch interaction was not significant, $F = .023, p = .881$ (Figure 6).

VJ – Vertec: The main effect for stretch condition on VJ as measured by the Vertec VJ system was not significant, $F_{1,22} = 1.201, p = .285$. The main effect for gender was significant $F_{1,22} = 68.168, p < .001$. The Gender x Stretch interaction was not significant, $F = .030, p = .864$ (Figure 7).

Quadriceps torque: The main effect for stretch condition on quadriceps torque was not significant, $F_{1,22} = .427, p = .520$. The main effect for gender was significant $F_{1,22} = 26.230, p < .001$. The Gender x Stretch interaction was not significant, $F = .050, p = .825$ (Figure 8).
Hamstring Torque: The main effect for stretch condition on hamstring torque was not significant, $F_{1,22} = .275$, $p = .605$. The main effect for gender was significant $F_{1,22} = 6.692$, $p = .017$. The Gender x Stretch interaction was not significant, $F = .008$, $p = .931$ (Figure 9).

These results suggest that static and ballistic stretching did not affect VJ, hamstring torque, or quadriceps torque. The Gender x Stretch interaction was not significant for any of the 4 measures above suggesting that the stretching conditions did not affect men and women differently. However, the significant main effect for gender, even when the variables were normalized for body weight, demonstrates that men produced more torque and VJ than women.

Power: The main effect for stretch condition on power was significant, $F_{1,22} = 7.124$, $p = .014$. The main effect for gender was significant, $F_{1,22} = 76.260$, $p < .001$. Once again, the Gender x Stretch interaction was not significant, $F = .779$, $p = .387$. These results indicate that the mean value for the control group was significantly greater than the two stretching conditions. Normalized means for power were 48.4, 48.9, and 50.1 for static, ballistic, and control respectively (Figure 10). These results showed that static and ballistic stretching had an adverse effect on power. The significant main effect for gender demonstrates that men produced more power than women.

Discussion

The purpose of this study was to determine if a realistic duration of acute static and ballistic stretching had any affect on measures of strength and power, and to compare the affects of stretching between genders. Static and ballistic stretching did not cause any changes to three out of the four measures when compared to the control condition. VJ,
quadriceps torque, and hamstring torque values were no different with the three stretch conditions. VJ was assessed with two different measures, a force plate and the Vertec VJ System. A correlation of 0.99 was found between these two measures, so the VJ results will be discussed as one.

A number of studies have reported that static stretching had a detrimental affect on VJ (4, 31, 36, 37) and torque output (1, 5, 9, 14, 19, 20, 21, 23). The exact mechanism for the stretch-induced decline in performance is not known, however authors have speculated that a decrease in muscle activation and MTU stiffness are the cause (1, 4, 9, 14, 17, 21, 22, 32). Power et al (23) found that static stretching of the plantar flexors, hamstrings, and quadriceps for 4.5 minutes each resulted in a 5.4% decrease in muscle activation, however the authors were not able to determine how long this decrease lasted. Studies that found muscle activation and MTU stiffness to decline for prolonged periods involved intense stretching that is not comparable to sports stretching due to their excessive length and concentration (1, 9). The results of this study conflict with these studies that found stretching to cause decrements in VJ and torque.

One reason for this discrepancy may be due to the difference in the design of the present study when compared to others. The present study was designed to test a practically relevant stretch duration similar to the routine used by athletes. This is the reason that subjects only stretched each muscle for 90 seconds total, 1 set of 3 repetitions, each held for 30 seconds. Most athletes do not spend prolonged periods of time stretching before activity. The previous mentioned studies (1, 5, 9, 14, 19, 20, 21, 23) all used study designs that required the muscle to be stretched for extended periods ranging from 8 to 30 minutes. Also, several of these studies focused only on one muscle.
example, Cramer et al (5) had subjects perform four different static stretches all focusing on the quadriceps held 30 seconds each and repeated four times. This stretching routine resulted in a total of 8 minutes stretching one muscle. The present study focused on two muscles, the quadriceps and the hamstrings, which were chosen because they could both be tested for torque output and both function as major muscles used in the VJ. The difference in 8 minutes devoted to a single muscle versus 3 minutes devoted to 2 muscles could certainly account for the differing results.

The results that static and ballistic stretching did not affect VJ, quadriceps and hamstring torque support the findings of other studies (2, 3, 13, 23, 30). Burkett et al (2) found that a static stretching routine of the lower body consisting of 14 stretches each held for 20 seconds caused no detrimental effects to VJ. Unick et al (30) found that static and ballistic stretching of the lower body lasting 3 minutes did not decrease VJ. The results of these studies and the present study indicate that a practical stretch duration of 90 seconds, similar to the stretch duration used by athletes, can be used pre-activity without adversely affecting VJ and torque output.

Wallmann et al (31) suggested that the specific muscles that are stretched might affect the VJ results. Wallmann et al (31) used the same stretch duration as the present study, however subjects only stretched the gastrocnemius. The result was a significant reduction in VJ. Similar to the present study, Church et al (3) used static stretching of the quadriceps and hamstrings, and it was determined that VJ was not affected by the static stretching routine. Further research should compare the effect of acute static stretching on VJ when different muscle groups are stretched.
One measure that was significantly affected by stretching was power. The results of the present study showed that both static and ballistic stretching caused a significant decline in power production when compared to the control condition that involved no stretching. Power was calculated with the GRF that were collected from the force plate while subjects performed the VJ test. VJ is commonly accepted as a predictor of power because in order to jump high a person needs to effectively generate force with their legs at a rapid speed. Surprisingly, the VJ test was not affected by the stretching routine as was power.

It was hypothesized that static and ballistic stretching would affect VJ and power equally. This however, was not the case in the present study. One potential explanation for this is the fact that the VJ requires a certain amount of skill and technique. Therefore, the VJ used in this study was comprised of three factors: force, speed, and technique. It is speculated that stretching does not have any affect on VJ technique. In comparison, raw power involves only force and speed. Therefore, the main difference in VJ and power is thought to be technique, and it is proposed that the stretching routine did not affect VJ due to the technique involved with the actual movement. For example, a person could adequately produce enough power to jump 30”, but if their technique is poor they will not effectively utilize the power to maximize their jump height. In the present study, power was significantly reduced, but did not cause any significant changes to VJ. It should be mentioned that the decrements, although significant, were relatively small.

Static stretching only caused a 3.4% decline and ballistic stretching only caused a 2.4% decline. Power et al (23) also found surprising results when subjects performed a static stretching routine that lasted 4.5 minutes per muscle. The results showed that the static
stretching routine adversely affected torque output and muscle activation of the quadriceps but did not however affect VJ. Power et al (23) concluded that the VJ was not affected because it was performed unilaterally and that these types of jumps possibly benefit from compliant MTU.

Based on the unusual results of this study one can speculate that the subjects' opinions about stretching could have influenced their VJ performance. It is a common belief that pre-activity static stretching is an important component of performance. Most people expect that if static stretching is performed pre-activity, performance will improve. This general belief may function as a “reverse placebo effect” as described by Knudson et al (13). In the present study, subjects were not informed of any hypothesis or provided information about their performance. Subjects were also not aware that their power output was being recorded at the time of the VJ. This common misconception about the effectiveness of stretching may have inadvertently affected performance.

Another significant finding from the study was the main effect for gender. These results showed that even when all values were normalized for body weight men produced significantly higher results than the women for all 4 variables. Unick et al (30) conducted a study using only women and suggested that further research was needed to determine if stretching affects the genders differently. Through the design of the present study it was possible to assess this. Despite the obvious performance differences between genders, it was determined that the static and ballistic stretching routine did not affect the genders differently. The performance of men was consistently and significantly higher than the performance of women for all three stretching conditions. Therefore, based on these results, when prescribing stretching for athletes, no consideration for gender is necessary.

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Practical Applications

Results of the present study revealed that acute pre-activity stretching does not affect genders differently when a practical stretch duration of 90 seconds is used. The results also revealed that acute static and ballistic stretching performed pre-activity does not affect VJ and torque output of the quadriceps and hamstrings. Coaches that utilize stretching as a part of the warm-up can continue to do so by limiting the duration of stretching to 1.5 minutes per muscle. However, since power was adversely affected sports that require maximal power output should not be preceded with acute stretching. Instead it is suggested that athletes perform a whole body continuous activity followed by dynamic stretching that involves rehearsal of sport specific movements. Dynamic stretching can function to properly prepare the athlete’s body for dynamic movements without the stretch-induced decrements that have been seen with pre-activity static and ballistic stretching (7, 8, 15, 34). If static stretching is used as a part of a training program it should be performed at the end of activity to increase range of motion (6, 14, 23) and improve performance (11, 22, 27, 33).
REFERENCES


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FIGURES LEGEND

Figure 1. Unilateral standing quadriceps stretch
Figure 2. Unilateral seated hamstrings stretch
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Figure 1. Unilateral standing quadriceps stretch

Figure 2. Unilateral seated hamstrings stretch
Figure 3. Counter movement jump on force plate

Figure 4. Vertec VJ system
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Figure 6. Effects of stretching on VJ (Force plate)

Figure 6.
Effects of stretching on VJ (Vertec)

![Graph showing effects of stretching on VJ (Vertec)](image)

**Figure 7.**

Effects of stretching on Quadriceps torque

![Graph showing effects of stretching on Quadriceps torque](image)

**Figure 8.**
Effects of stretching on Hamstring torque

Figure 9.

Effects of stretching on Power

Figure 10.
APPENDIX 2

STRETCHING TO IMPROVE SPORTS PERFORMANCE. WHEN IS IT OK TO STRETCH PRIOR TO ACTIVITY?
A clear picture does not exist for strength coaches regarding the effectiveness of stretching. The cause for confusion appears to be two-fold. First, generalizations are made regarding the type, timing and purpose of stretching. For example, strength coaches may hear the generalization that stretching actually has an adverse affect on performance. This sweeping generalization is simply not supported. However, if an athlete is using static stretching immediately prior to an activity requiring power production then a decrease in performance is likely. Secondly, the results of scientific research are not consistent which leaves the strength coach with questions. Therefore, the purpose of this paper is to address the types, timing and purpose of stretching and to provide guidance for strength coaches based on the available scientific literature.

Types of Stretching

The three most common types of stretching include static, ballistic, and dynamic. Static stretching occurs when a muscle is lengthened to a tolerable limit and is held in that position for a specified period of time. Static stretching is considered to be a safer form of stretching than ballistic because it does not involve any fast movements and is performed in a controlled manner (16, 24, 34). Ballistic stretching occurs when the muscle is lengthened and the momentum of a moving extremity further lengthens the muscle beyond its normal range of motion (ROM). This type of stretching consists of a subject performing repetitive bouncing movements at the involved joint. A third type of stretching that has recently entered the research field is dynamic stretching. Dynamic stretching can easily be confused with ballistic stretching, they are however very different. Dynamic stretching involves contraction of the agonist, which will stretch the antagonist as the end of the ROM is reached. This type of stretching differs from
ballistic because it does not involve bouncing movements; rather all movements should be performed in a controlled manner. Dynamic stretching involves a rehearsal of sport specific movements that are to be performed in the applicable sport. For example, soccer players could jog with high knees, which would focus on actively contracting the hip flexors while stretching the hip extensors. Or a football kicker could perform a place kick without the football, which would focus on stretching the hamstring and groin muscles while the athlete is able to practice this sports specific movement. Many authors do not separate each type of stretching and specify which type they are discussing; this can easily cause confusion for strength coaches when deciding which type of stretching is best.

**Time for Stretching**

Another confusing generalization is the time at which stretching is performed. The research mainly focuses on pre-activity stretching, which refers to stretching that is performed during the warm-up routine. This type of stretching can be performed at two different times during the warm-up. The most common time it is performed is after some form of whole body continuous activity, such as jogging. The other time that pre-activity stretching can be performed is at the very beginning of the warm-up before any activity is completed. The majority of research focuses on acute stretching that is performed pre-activity, however some references to the effect of stretching are dealing with benefits of long term stretching. Long term stretching refers to stretching that is performed after physical activity on a continual weekly basis. Fewer studies have been completed on the long term effect of stretching on performance, but according to these studies long term
stretches that are not performed prior to activity can improve VJ, power, MVIC, and torque output (15, 33, 38).

**Purpose for Stretching**

One limitation that exists in the stretching literature is the purpose or desired goal of a stretching routine. Most authors do not consider this when discussing the results of a study yet recommendations on whether or not one should stretch are made. These recommendations should be based on the type of activity to be performed. This can cause confusion for strength coaches when designing a training program. Strength coaches include stretching in a training program for different reasons. Two of the most common reasons athletes stretch are to increase ROM and to properly prepare the body for powerful dynamic movements. Different sports require different stretch parameters yet the goals and actual effect of stretching are not always considered. Due to the difference in goals the same type and timing of stretching should not be performed for all athletes.

**Effectiveness of Pre-activity Stretching**

Many coaches have had to decide whether to stretch or not to stretch due to inconsistent scientific research about the effects of pre-activity stretching on performance. Although much research has been conducted in regards to stretching, there is a lack of agreement of whether pre-activity stretching is beneficial or detrimental. Some studies have found that pre-activity stretching actually hinders some performance factors such as maximum voluntary isometric contraction (MVIC) (2, 13, 29), vertical jump (VJ) (7, 22, 36, 41, 42), torque output (8, 10, 18, 21, 27), power (21), and sprint time (12). While other studies have found that pre-activity stretching does not negatively
affect sports performance (1, 5, 6, 17, 29, 35, 39). Although many exercise professionals promote pre-activity static stretching for improved performance, the scientific evidence to justify this belief is limited. The only scientific studies that determined pre-activity stretching improved performance involved dynamic stretching as the performance enhancing warm-up. No research has found that pre-activity static or ballistic stretching improves performance.

Many authors have suggested that athletes incorporate sport specific movements into their warm-up routine for improved performance (11, 12, 23, 39, 41). Young et al (41) suggested this based on their results that showed the two best warm-up methods for improved performance were sub-maximal running and running followed by static stretching and four practice VJs. These two methods resulted in the greatest force production and jump performance. The lowest performance was found with the group that performed only static stretching as their warm-up. Yamaguchi et al (39) compared the effect of static and dynamic stretching on leg extension power and found that leg extension power was significantly increased following the dynamic stretching routine and unaffected after the static stretching routine. Fletcher et al (12) found that performing an active dynamic stretch routine prior to 20 meter sprints resulted in significantly faster sprint times. However, when an active static and passive static stretch routine was performed prior to 20 meter sprints, the sprint time was significantly slower.

**Dynamic stretching to improve performance**

In order for athletes to obtain success in many sports dynamic movements are required. An important part of obtaining this success is the warm-up routine. An athlete must properly prepare the body for dynamic movements, without a proper warm-up poor
performance and even injury could result. It is suggested that athletes include the following in their warm-up for activities that involve dynamic movements and rely on maximal force production: a whole body continuous activity and dynamic stretching that involves rehearsal of sport specific movements. Dynamic stretching involves muscular contractions, which generate heat and raise the temperature of intramuscular tissues (37). It is thought that dynamic stretching increases core temperature more significantly than other stretching methods (12). This increase in tissue temperature should allow increases in ROM (31), velocity of muscular contraction, and force production (3, 12). Yamaguchi and Ishii (39) investigated dynamic stretching of the plantar flexors, knee flexors, knee extensors, hip flexors, and hip extensors. The dynamic stretching consisted of subjects contracting the antagonist of each muscle once every 2 seconds. This was completed 5 times slowly and 10 times as fast and as explosive as possible without causing any bouncing movements. Based on the results, the authors concluded that power performance would benefit if dynamic stretching were added to the warm-up routine. To add dynamic stretching the warm-up should begin with a whole body continuous activity (i.e. 5-10 minute jog). Following this several sport specific dynamic stretches should be selected that take approximately 10 minutes to perform (Table 1). The dynamic stretches selected should progress from low to moderate to high intensity (11). Stretches that are selected for the lower extremity should consist of 2 sets of 15 repetitions for each leg, with a 10-15 second rest between, lasting approximately 1 minute. Sports that would benefit from this type of workout include track and field, power lifting, soccer, football, and basketball. These sports that rely on strength and power should avoid static and ballistic pre-activity stretching and should instead use dynamic stretching.
Stretching for specific sports

The effect of pre-activity static stretching will likely depend on the type of activity to be performed. Some sports require athletes to perform movements that necessitate excessive joint ROM (37). Activities that require movements with extreme ROM may benefit from static stretching. These activities mainly focus on the flexibility of the athlete and not necessarily on their ability to produce maximal force output. The decreases in performance (2 -5%) that have been seen following acute stretching may not be detrimental to an athlete that needs to be able to externally rotate their shoulder past 90° (33). The effect that static stretching may have on their force production may not be as significant to their sports performance as their ability to move effectively. Some examples of these sports are gymnastics, diving and dancing. Sports such as these rely on stretching in order to prepare their joints and musculature for their sports specific activities. These sports can continue with stretching and even avoid the decrease in performance that has been seen with many studies (2, 13, 18, 21, 22, 26, 27, 28, 29, 32, 40). This can be accomplished by taking advantage of the long term effects of stretching. Several studies have found that stretching not performed directly before activity will increase ROM (9, 23, 34) and improve performance (15, 32, 33, 38). To attain these benefits sports teams can perform a static stretching routine during the cool down phase or after practice.

For the many strength coaches that have long held the belief that stretching needs to be preformed before activity, some studies have found that this can still be done (1, 5, 6, 17, 29, 35, 39). In order to incorporate static stretching into pre-activity routines, one should begin the warm-up routine with stretching (4, 30). Most athletes begin the warm-
up with some form of continuous whole body activity first, followed by static stretching. This routine has been shown to cause declines in sports performance (2, 8, 13, 18, 21, 24, 26, 27, 29). If an athlete stretches first and then performs a continuous whole body activity such as a 5 – 10 minute run, the detrimental effects seen with stretching would diminish by the time the athlete is ready to perform. It was found that performing a continuous whole body activity, such as jogging, after stretching helps to recoil the MTU which functions to “take up the slack” that is so commonly found following stretching, allowing the muscle to regain its ability to effectively generate force (4,30). Unick et al (35) proposed that the adverse effects of a 3 minute static stretching routine did not affect VJ because subjects performed a 4 minute walk immediately following stretching. Unick et al (35) hypothesized that any changes that may have occurred as a result of stretching were no longer present following the 4 minute walk.

Some of the detrimental effects seen with stretching are a decrease in muscle activation and an increase in musculotendinous (MTU) stiffness, which decreases the ability of the muscle to produce maximal force. Researchers that have studied these detrimental effects have found that pre-activity stretching routines that last 6 minutes or less did not cause a decrease in muscle activation (10, 21). Power et al (29) found that static stretching of the plantar flexors, hamstrings, and quadriceps for 4.5 minutes each resulted in a 5.4% decrease in muscle activation, however the authors of this study were not able to determine how long this decrease lasted. Studies that found muscle activation and MTU stiffness to decline for prolonged periods involved intense stretching that is not comparable to sports stretching due to their excessive length and concentration (2, 13). Pilot data showed that a stretching protocol consisting of 1 set of 3 repetitions of static
stretching held for 30 seconds did not affect measures of strength. Davis et al (9) determined that performing 1 repetition of static stretching for 30 seconds 3 times a week was sufficient enough to increase hamstring flexibility. Therefore the recommended static stretching routine includes 1 set of 3 repetitions with each repetition held for 30 seconds. This routine can be performed for each muscle group lasting 1.5 minutes per muscle. This routine should be performed after physical activity as part of the cool down to benefit from the long-term effects of stretching. If the activity to be performed relies on pre-activity stretching to prepare the body for movements that require excessive ROM, then this same routine can be performed as the first part of the warm-up followed by a whole body continuous activity.

Conclusion

The only type of pre-activity stretching that has been found to improve performance is dynamic stretching, which involves a rehearsal of sports specific movements. It is suggested by many authors that acute static stretching should not be performed prior to physical activity, especially when those activities involve maximal strength and power performance (4, 8, 18, 23, 30, 33). For sports that involve dynamic, explosive movements it is recommended that dynamic stretching is added to the warm-up routine and designed based on the involved sport. For certain sports that necessitate stretching prior to activity due to ROM requirements, it is recommended that the stretching routine should last less than 10 minutes and be followed by a whole body continuous activity.
Table 1. Examples and explanation of dynamic stretches

<table>
<thead>
<tr>
<th>Dynamic Stretch</th>
<th>Primary muscles</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>High Knees</td>
<td>Quadriceps, glutes</td>
<td>In a walking movement raise knee towards the chest while swinging the arms</td>
</tr>
<tr>
<td>Walking straight leg march</td>
<td>Hamstrings, gastrocnemius</td>
<td>In a walking movement with the leg extended and foot plantar flexed, lift leg towards chest while simultaneously reaching with opposite hand to touch the toes</td>
</tr>
<tr>
<td>Butt kicks</td>
<td>Quadriceps, hip flexors</td>
<td>In a jogging pace, flex the knees and bring heels towards buttocks while leaning forwards</td>
</tr>
<tr>
<td>Carioca</td>
<td>Abductors, adductors</td>
<td>Body will be in a partially squatted position while crossing the first leg in front of the other by twisting the hips and bringing back leg forwards, then cross the first leg behind the other</td>
</tr>
<tr>
<td>Explosive skipping</td>
<td>Whole body</td>
<td>In a skipping movement the knees should be explosively lifted while swinging the arms. While performing this movement height should be focused on rather than distance.</td>
</tr>
<tr>
<td>Arm swings</td>
<td>Pectoralis muscles, biceps</td>
<td>The arms should be swung forwards by bending the elbows and crossing the arms at the chest, then swinging the arms backwards by extending the elbows</td>
</tr>
</tbody>
</table>
REFERENCES


APPENDIX 3

COMPLETE BIBLIOGRAPHY


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